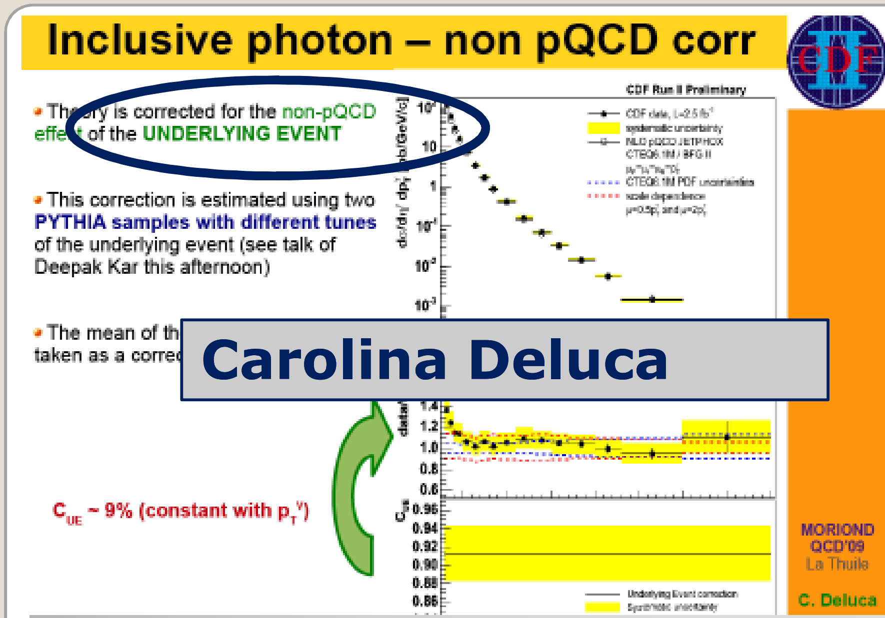
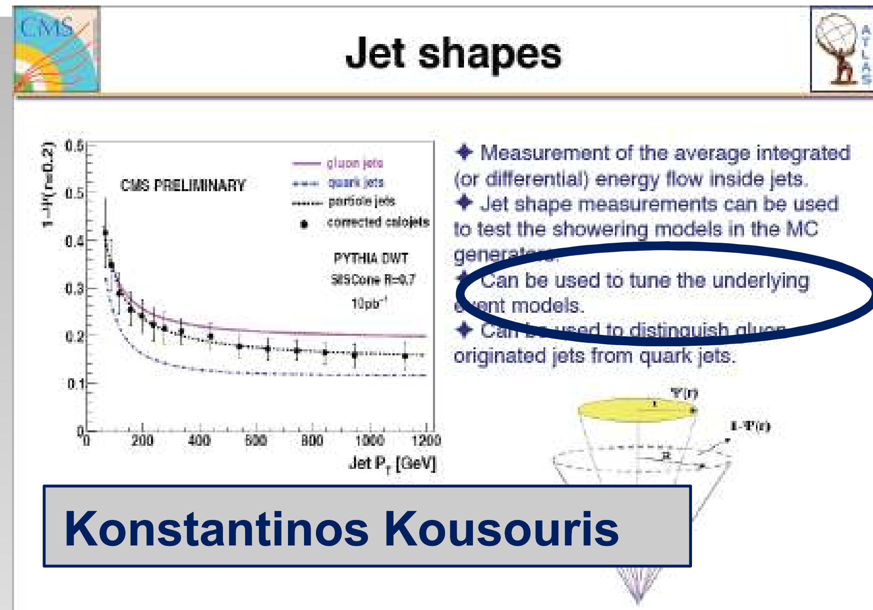
18th March, 2009
QCD Session

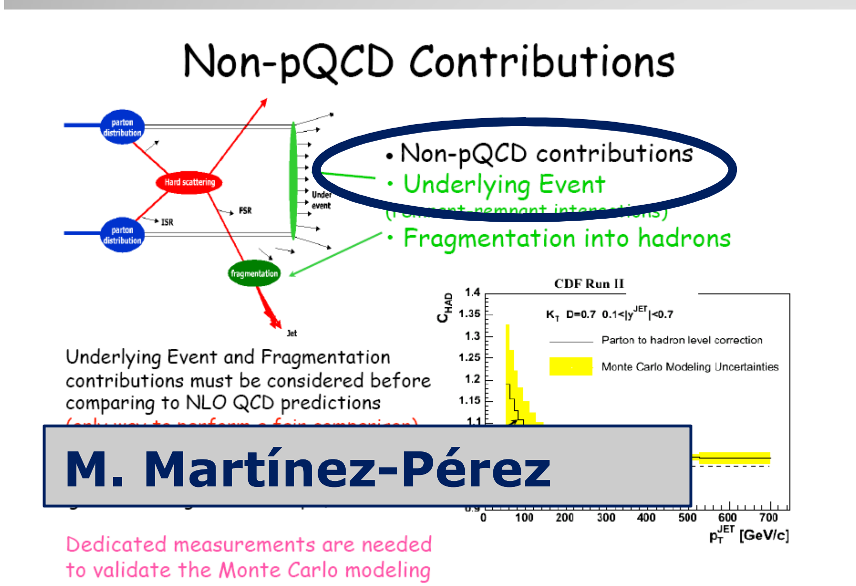
Measurement of the Underlying Event at Tevatron

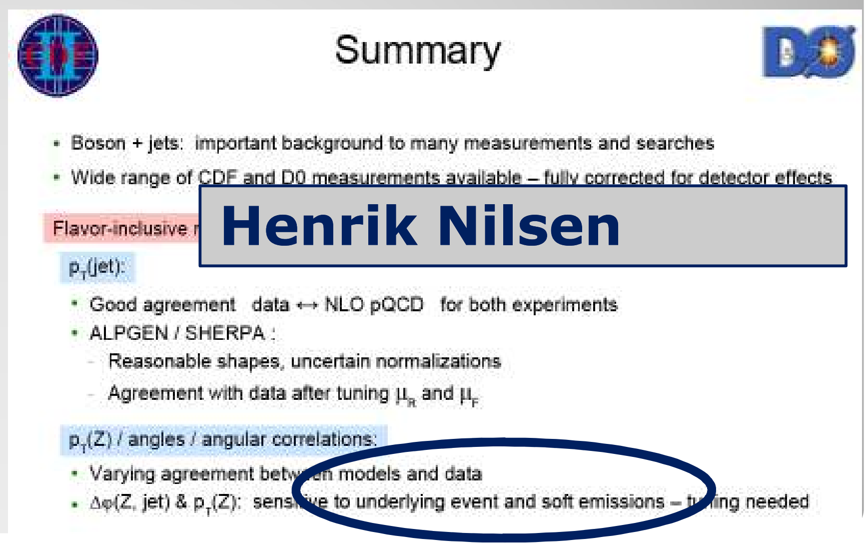
Deepak Kar

TU Dresden / University of Florida
(On behalf of the CDF Collaboration)


Inclusive photon – non pQCD corr
Theory is corrected for the non-pQCD effect of the UNDERLYING EVENT
This correction is estimated using two PYTHIA samples with different tunes of the underlying event (see talk of Deepak Kar this afternoon)
The mean of th
taken as a correc
Carolina Deluca
C_UE ~ 9% (constant with p_T^γ)
CDF Run II Preliminary
MORIOND QCD'09 La Thuile
C. Deluca


Jet shapes
CMS PRELIMINARY
gluon jets
quark jets
particle jets
corrected calojets
PYTHIA DWT
SISCone R=0.7
10pb⁻¹
Jet P_T [GeV]
Measurement of the average integrated (or differential) energy flow inside jets.
Jet shape measurements can be used to test the showering models in the MC generators.
Can be used to tune the underlying event models.
Can be used to distinguish gluon originated jets from quark jets.
Konstantinos Kousouris


Non-pQCD Contributions
Non-pQCD contributions
Underlying Event
(remnant-remnant interactions)
Fragmentation into hadrons
Underlying Event and Fragmentation contributions must be considered before comparing to NLO QCD predictions
M. Martínez-Pérez
CDF Run II
Parton to hadron level correction
Monte Carlo Modeling Uncertainties
Dedicated measurements are needed to validate the Monte Carlo modeling

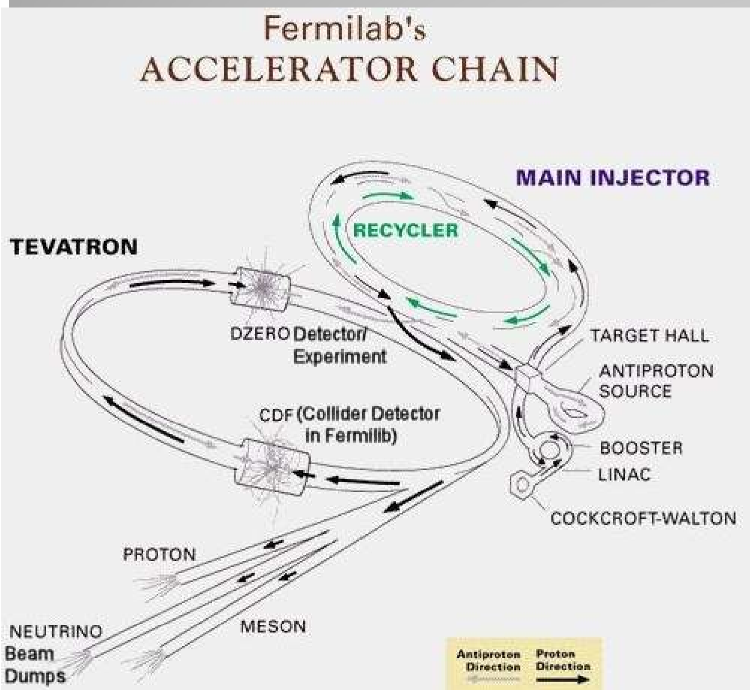

Summary
Boson + jets: important background to many measurements and searches
Wide range of CDF and D0 measurements available – fully corrected for detector effects
Flavor-inclusive
Henrik Nilsen
p_T(jet):
Good agreement data ↔ NLO pQCD for both experiments
ALPGEN / SHERPA :
Reasonable shapes, uncertain normalizations
Agreement with data after tuning μ_R and μ_F
p_T(Z) / angles / angular correlations:
Varying agreement between models and data
Δφ(Z, jet) & p_T(Z): sensitive to underlying event and soft emissions – tuning needed

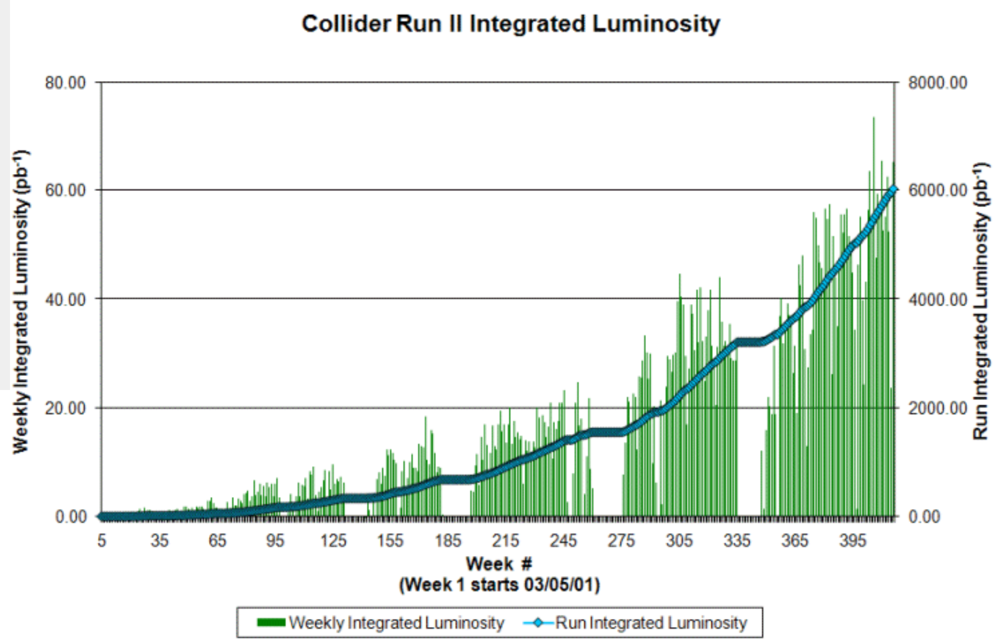
Motivation:

- Need to be able to simulate "ordinary" QCD and "Standard Model" events at the collider.

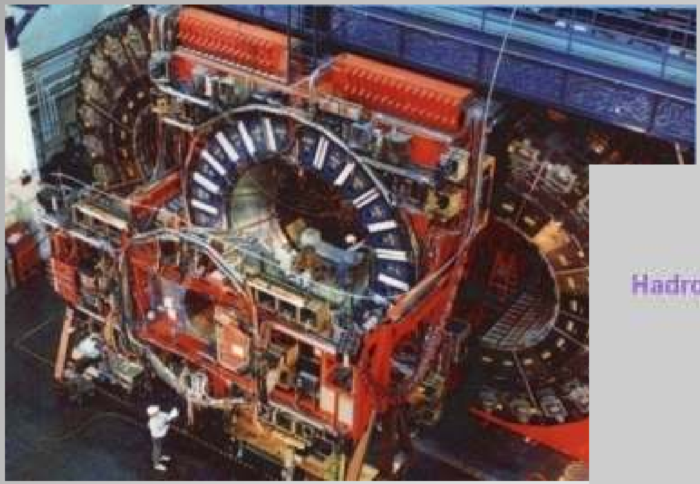
- Finding "new" physics requires a good understanding of the "old" Physics (Not only to have a good model of the hard scattering part of the process but also of "underlying event").

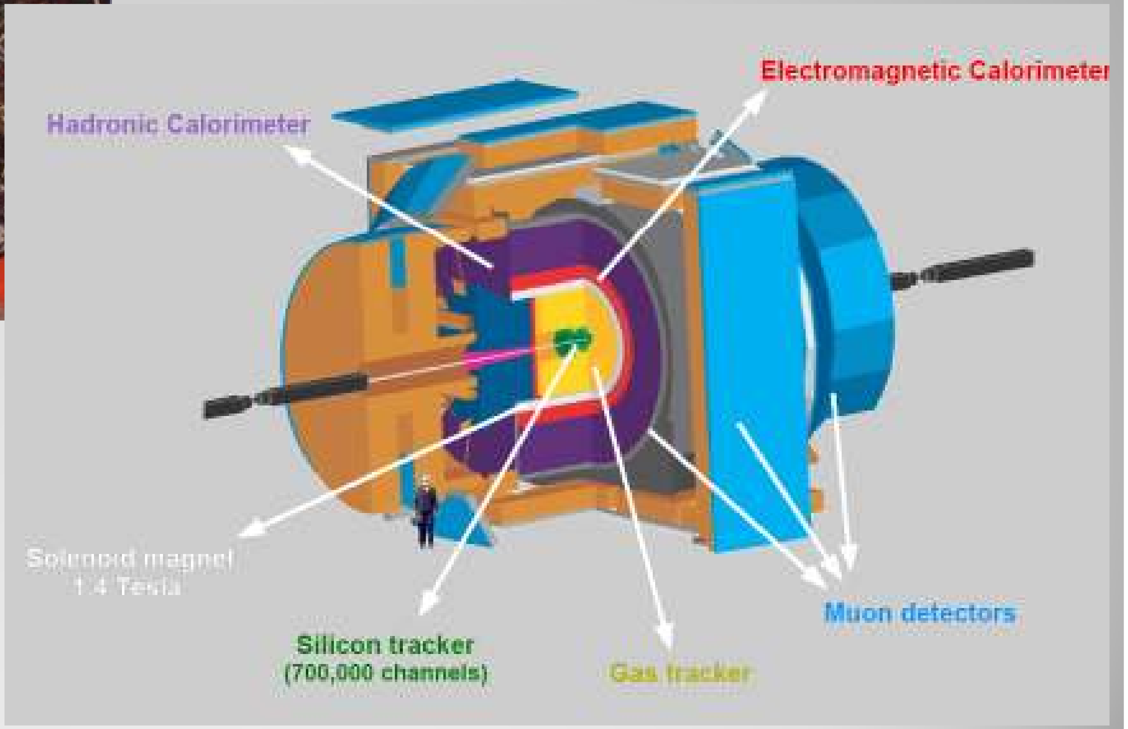
TeVatron


Fermilab's
ACCELERATOR CHAIN
MAIN INJECTOR
RECYCLER
TEVATRON
DZERO Detector/
Experiment
TARGET HALL
ANTIPROTON
SOURCE
CDF (Collider Detector
in Fermilib)
BOOSTER
LINAC
COCKCROFT-WALTON
PROTON
NEUTRINO
Beam
Dumps
MESON
Antiproton Direction
Proton Direction

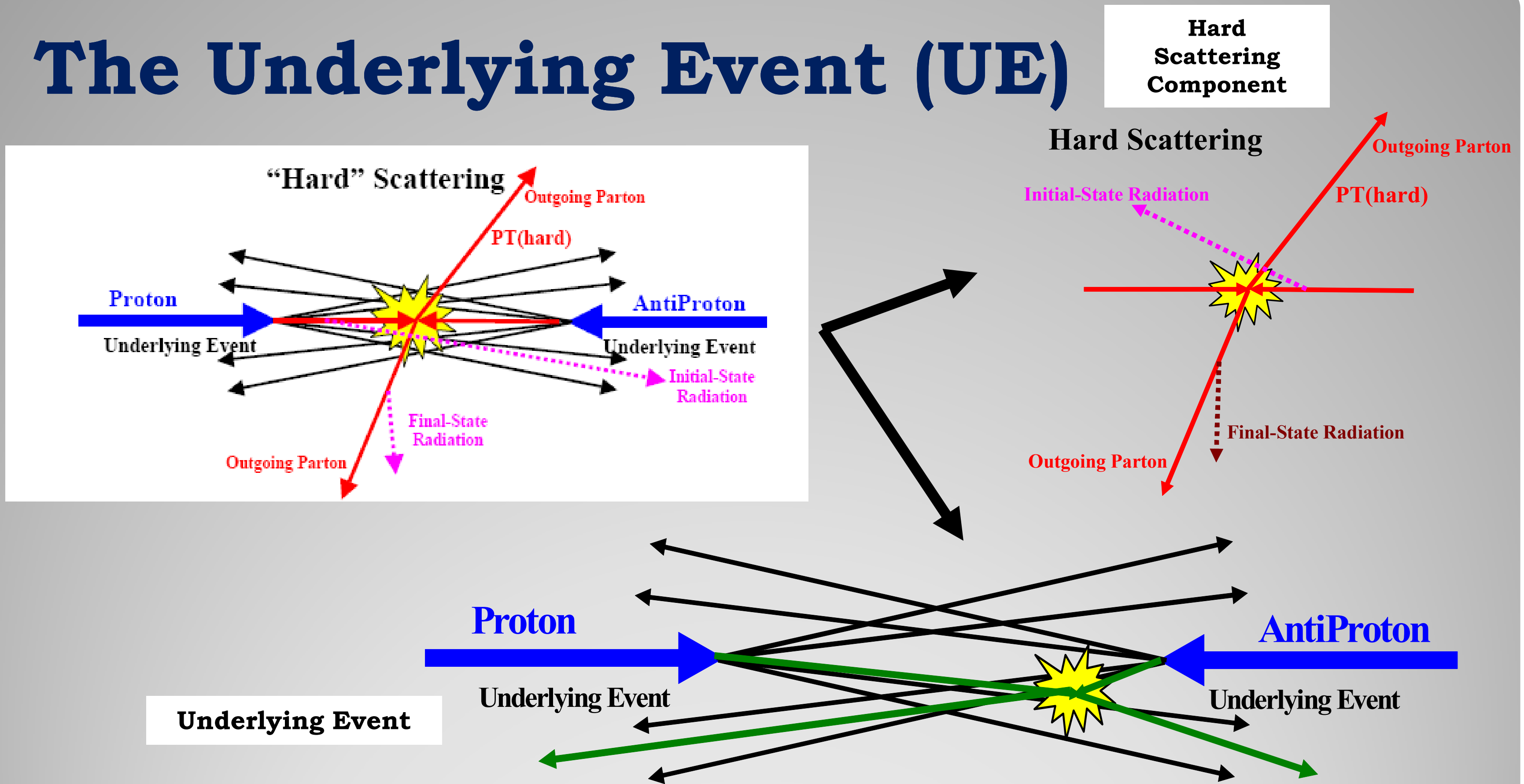

Collider Run II Integrated Luminosity
Weekly Integrated Luminosity (pb⁻¹)
Run Integrated Luminosity (pb⁻¹)
0.00
20.00
40.00
60.00
80.00
0.00
2000.00
4000.00
6000.00
8000.00
5
35
65
95
125
155
185
215
245
275
305
335
365
395
Week #
(Week 1 starts 03/05/01)
Weekly Integrated Luminosity
Run Integrated Luminosity

Collider Detector at Fermilab (CDF)



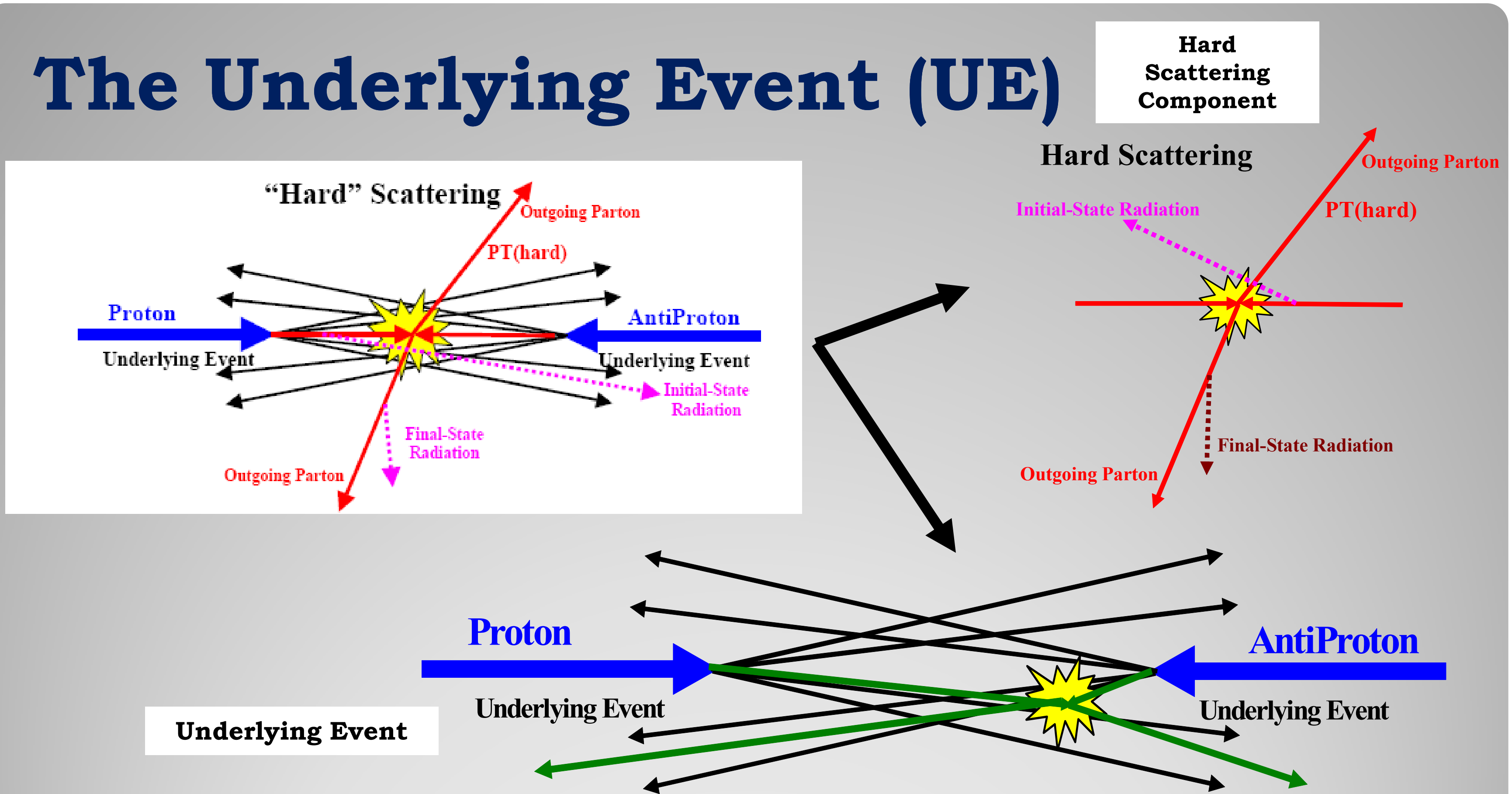


The Underlying Event (UE)



Everything except the two outgoing hard scattered components.
Beam-beam remnants (BBR), multiple parton interactions (MPI) …

The Underlying Event (UE)



From an experimental point of view, on an event by event basis, it is impossible to separate these two components.

So what is the problem with the Underlying Event ?

- The process of interest at hadron colliders are mostly the hard scattering events.
- These hard scattering events are contaminated by the underlying event.
- The underlying event is an **unavoidable background** to most collider observables.
- Increasing luminosity implies more hadronic collisions – which also complicates things. ***(pile-up)***
- The underlying event is not well understood since **non-perturbative physics** is involved.

Measuring it is important in …

- Precision measurements of hard interactions where soft effects need to be subtracted.

- Jet cross-section, missing energy, isolation cuts, top mass …

- QCD Monte-Carlo tuning.

Higher the precision, higher the accuracy of physics measurements.

PYTHIA

For underlying event studies, the only tool we have is to compare the data and the **predictions** from various Monte Carlo event generators, i.e. PYTHIA.

Apollo's priestess, Pythia, performing the duty of the oracle

PYTHIA has "knobs" which can be *tuned* to obtain an optimal description of the data.

PYTHIA Parameters

PYTHIA UE Parameter	Definition
MSTP(81)	MPI on/off
MSTP(82)	3 / 4: resp. single or double gaussian hadronic matter distribution in the p / pbar
PARP(67)	ISR Max Scale Factor
PARP(82)	MPI pT cut-off
PARP(83)	Warm-Core: parp(83)% of matter in radius parp(84)
PARP(84)	Warm-Core: ”
PARP(85)	prob. that an additional interaction in the MPI formalism gives two gluons, with colour connections to NN in momentum space
PARP(86)	prob. that an additional interaction in the MPI formalism gives two gluons, either as described in PARP(85) or as a closed gluon loop. Remaining fraction is supposed to consist of qqbar pairs.
PARP(89)	ref. energy scale
PARP(90)	energy rescaling term for PARP(81-82)~E_{CM}^PARP(90)

PYTHIA Parameters

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PARP(82)	MPI pT cut-off

- PYTHIA uses MPI to enhance the UE.
- Multiple parton interaction more likely in a hard (central) collision.
- ISR Max Scale Factor affects the amount of initial-state radiation.
- Increasing the cut-off decreases the multiple parton interaction.

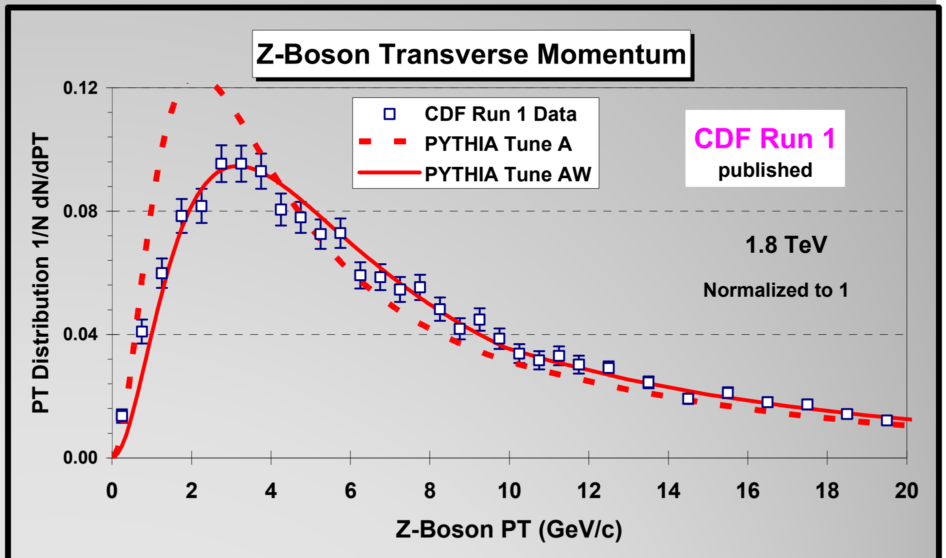
CDF Run 1 Tune (PYTHIA 6.2 CTEQ5L)

UE Parameters

ISR Parameters

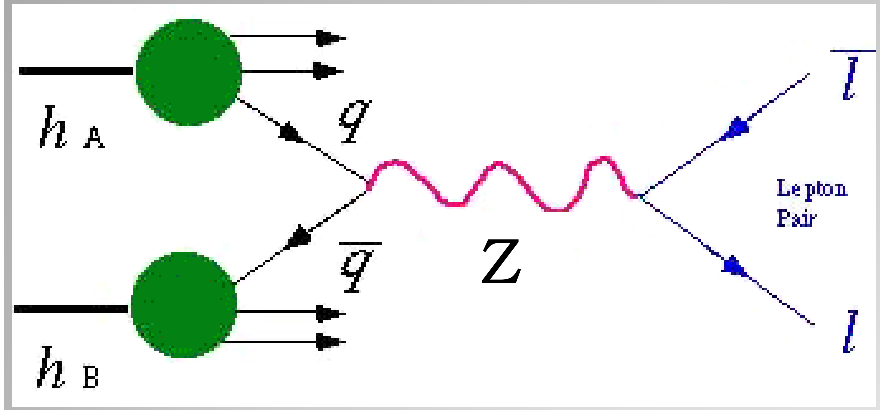
Intrinsic KT

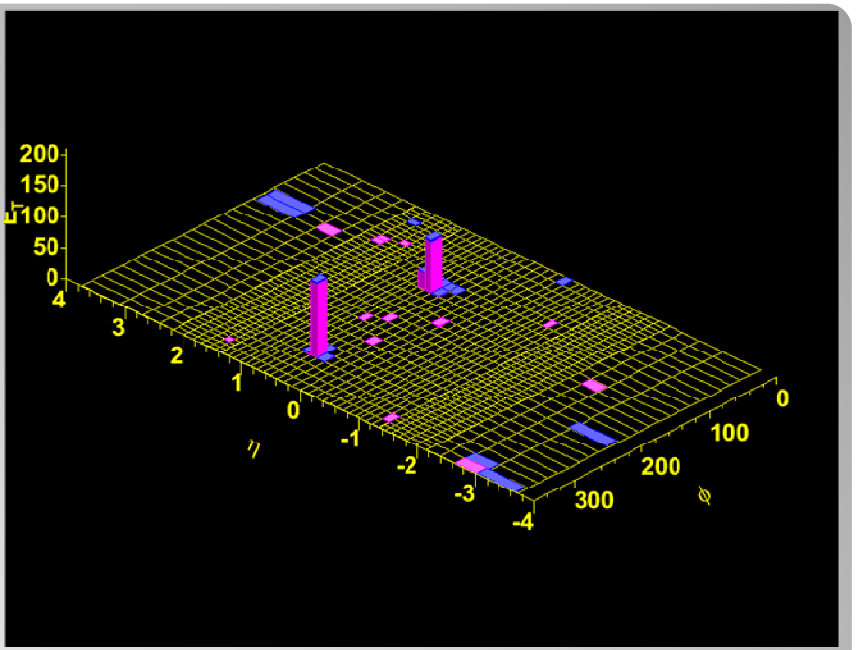
Parameter	Tune A	Tune AW
MSTP(81)	1	1
MSTP(82)	4	4
PARP(82)	2.0 GeV	2.0 GeV
PARP(83)	0.5	0.5
PARP(84)	0.4	0.4
PARP(85)	0.9	0.9
PARP(86)	0.95	0.95
PARP(89)	1.8 TeV	1.8 TeV
PARP(90)	0.25	0.25
PARP(62)	1.0	1.25
PARP(64)	1.0	0.2
PARP(67)	4.0	4.0
MSTP(91)	1	1
PARP(91)	1.0	2.1
PARP(93)	5.0	15.0



Both tunes reveal a remarkably good agreement of the data and PYTHIA.

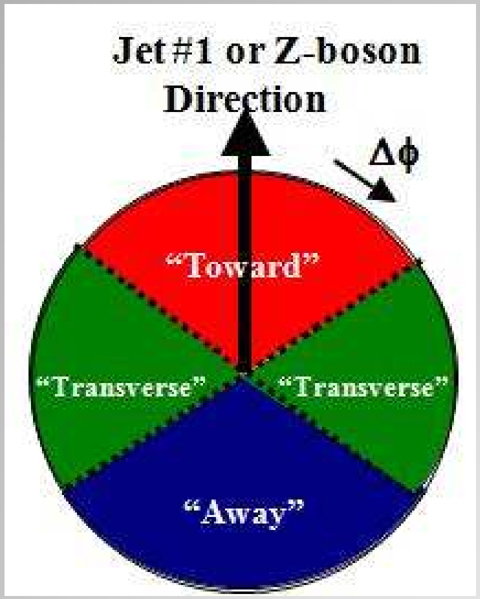
Drell-Yan Process





- Charged particles with: p_T > 0.5 GeV/c and $|\eta|$ <1
- Using events with the lepton pair invariant mass in the Z region: 70 < M(ll) < 110 GeV/c^2

Dividing up the Central Region



We define –

- $|\Delta\phi| < 60^o$ as **Toward**
- $60^o < |\Delta\phi| < 120^o$ as **Transverse**
- $|\Delta\phi| > 120^o$ as **Away**

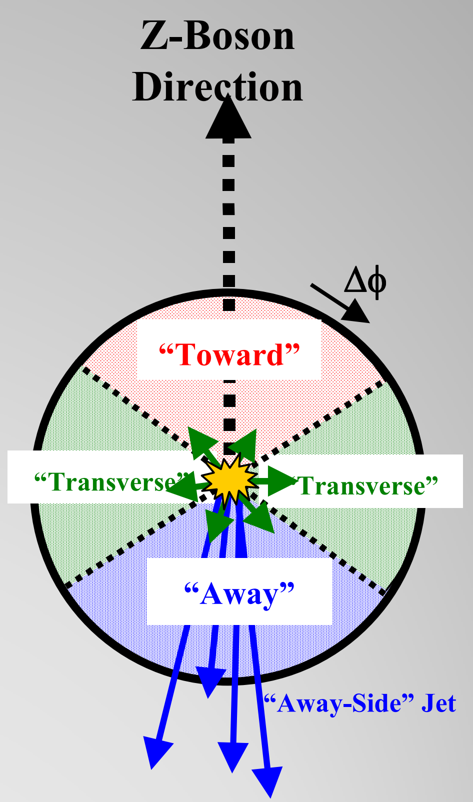
Azimuthal angle $\Delta\phi$ relative to the leading calorimeter jet (or the Z-boson)

Z-Boson Production at Tevatron

Single Z Bosons are produced with large p_T via the ordinary QCD sub processes:

$$qg \rightarrow Zq,\ q\bar{q} \rightarrow Zg,\ \bar{q}g \rightarrow Z\bar{q}$$

They generate additional gluons via bremsstrahlung – resulting in multi-parton final states **fragmenting into hadrons** and forming **away-side jets**.



	CDF (pb)	NNLO (pb)
$\sigma(Z\rightarrow l^+l^-)$	254.9±3.3(stat)±4.6(sys)±15.2(lum)	252.3±5.0

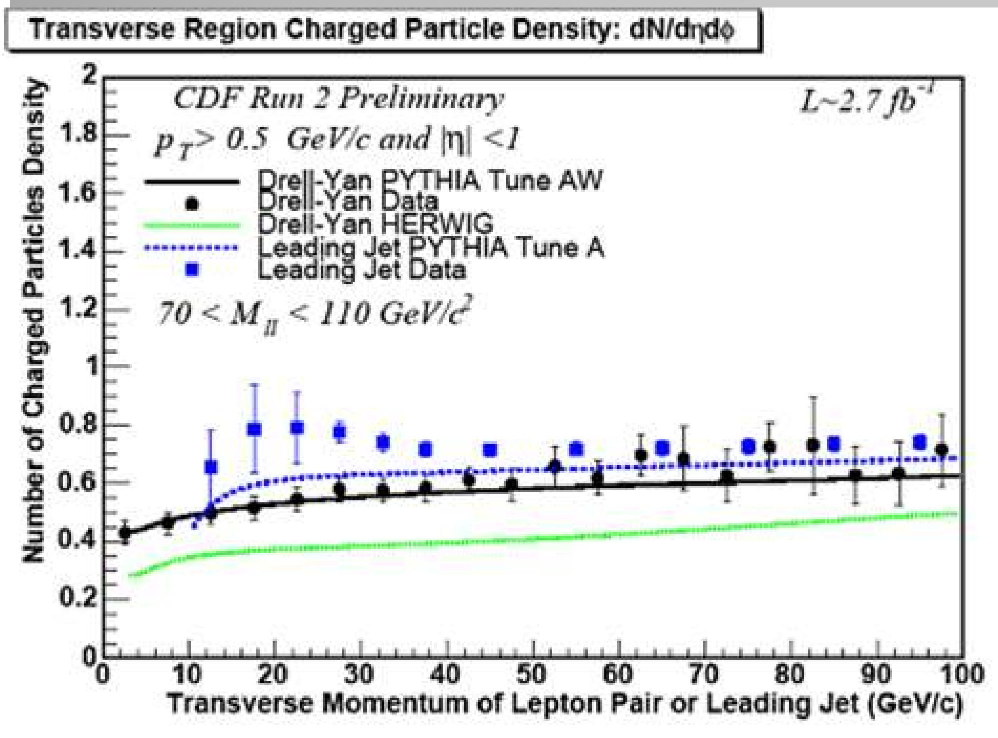
CDF: Phys. Rev. Lett. 94, 091803 (2005)
NNLO Theory: Stirling, Van Neerven

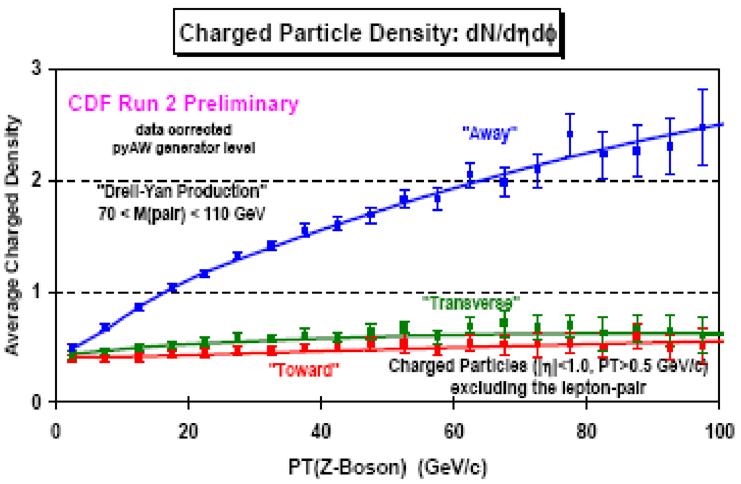
Our Analysis

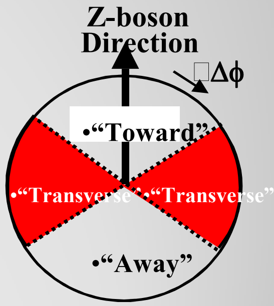
- The goal of the analysis was to produce data on the **underlying event** that is **corrected** to the particle level so that it can be used to **tune** the QCD Monte-Carlo models without requiring CDF detector simulation (i.e. CDFSIM).

- Also by looking at the measurements sensitive to the underlying event, we would be able to **better constrain** our underlying event models.

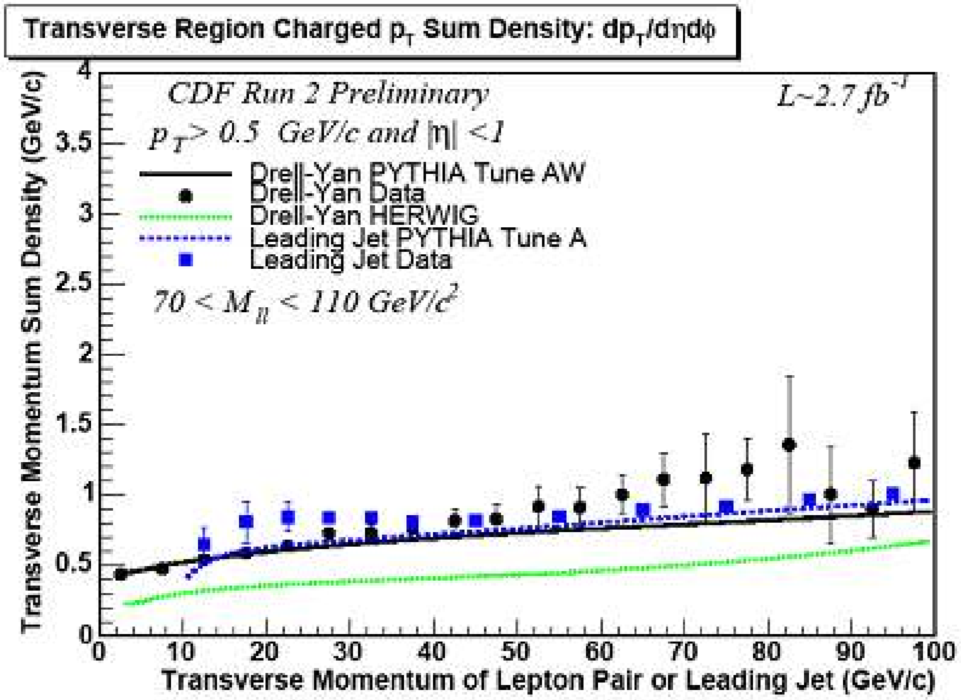
Charged Particle Multiplicity

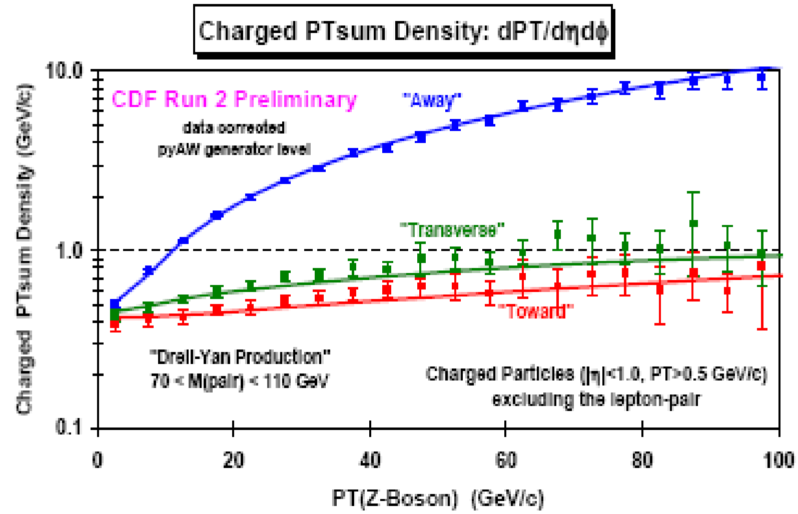


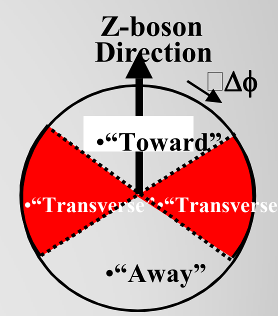




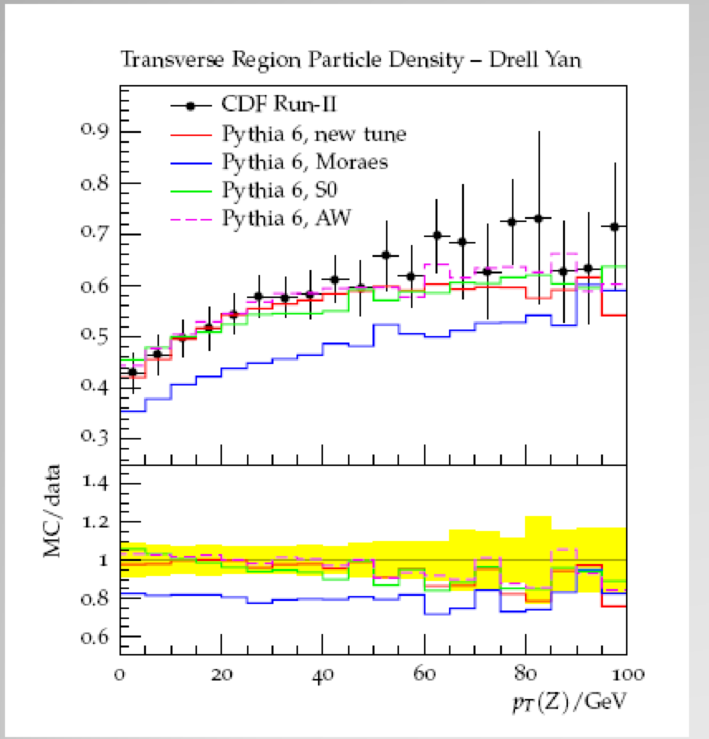
Charged Transverse Momentum Sum

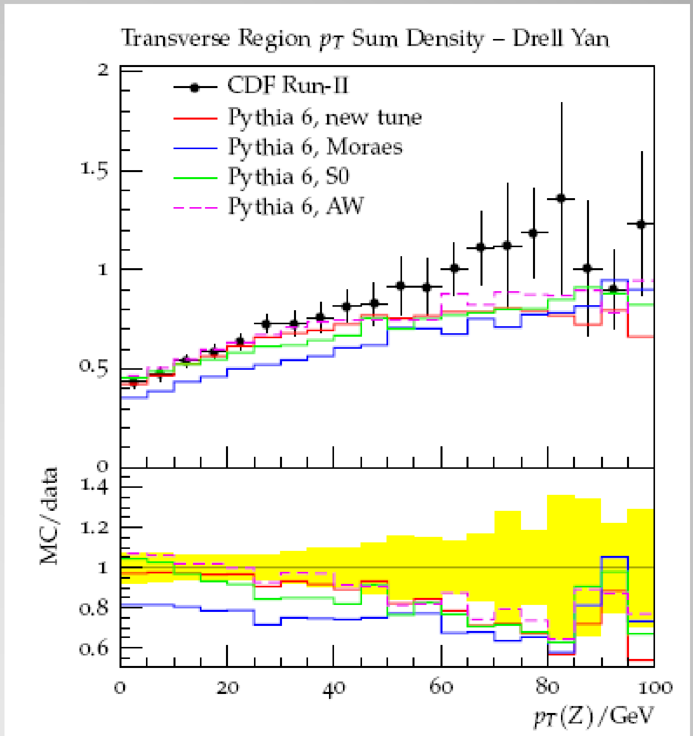






"Newer" Tunes
(From H. Hoeth, MPI@LHC 2008)





Data/MC comparisons show the features and problems of different generators and tunings.

Mean p_T vs Charged Multiplicity

$\langle p_T \rangle$ versus N_{chg} is a measure of the amount of **hard versus soft** processes contributing and it is **sensitive** to the modeling of the multiple-parton interactions.

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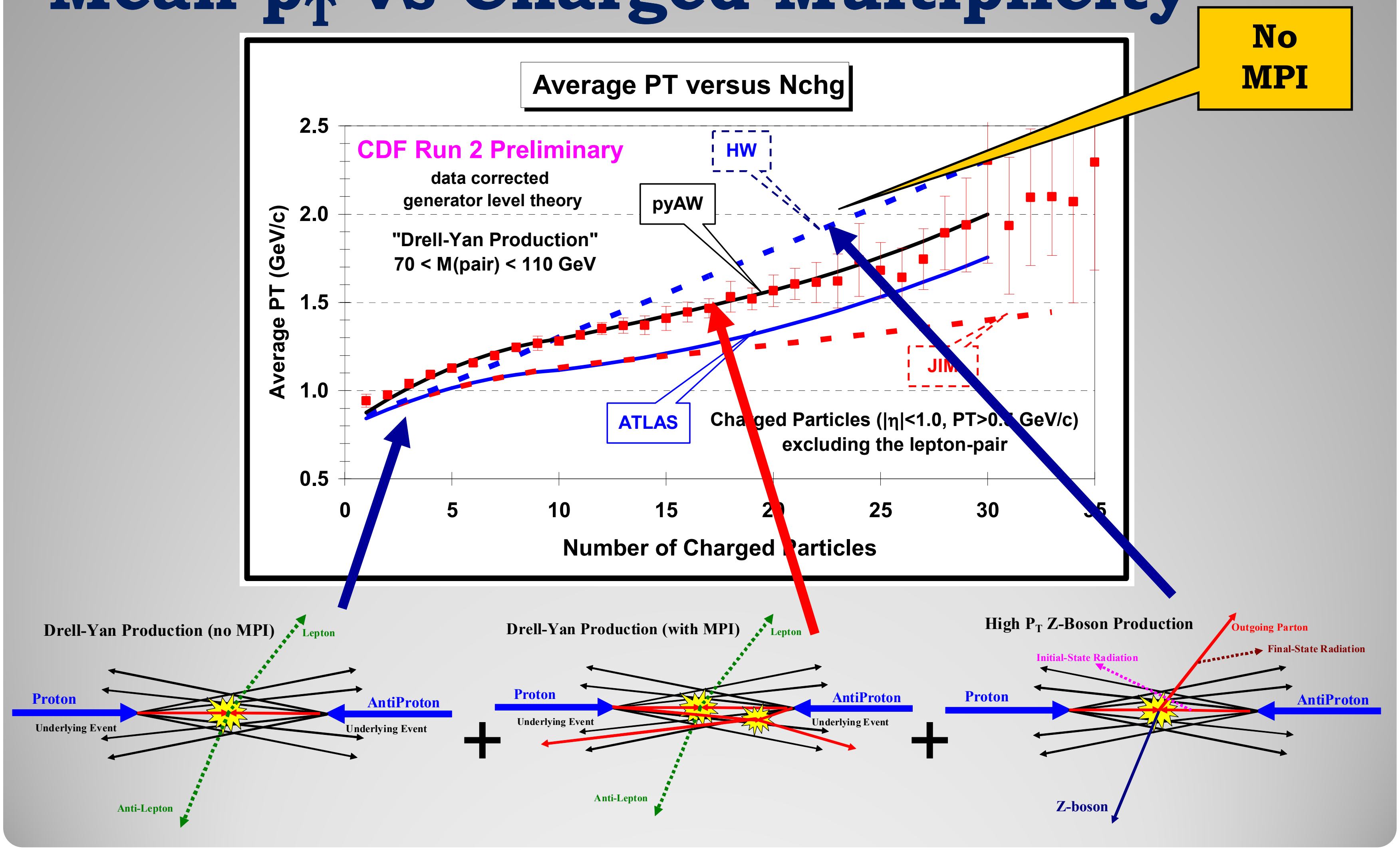
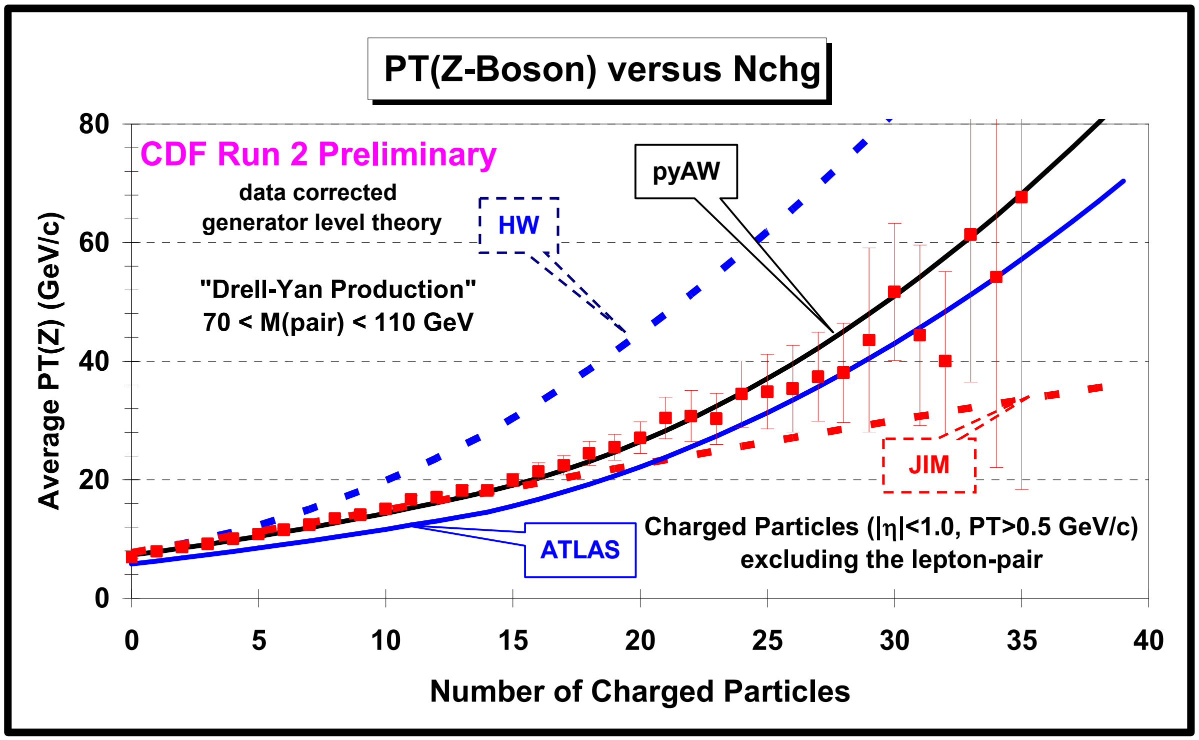
Mean p_T vs Charged Multiplicity



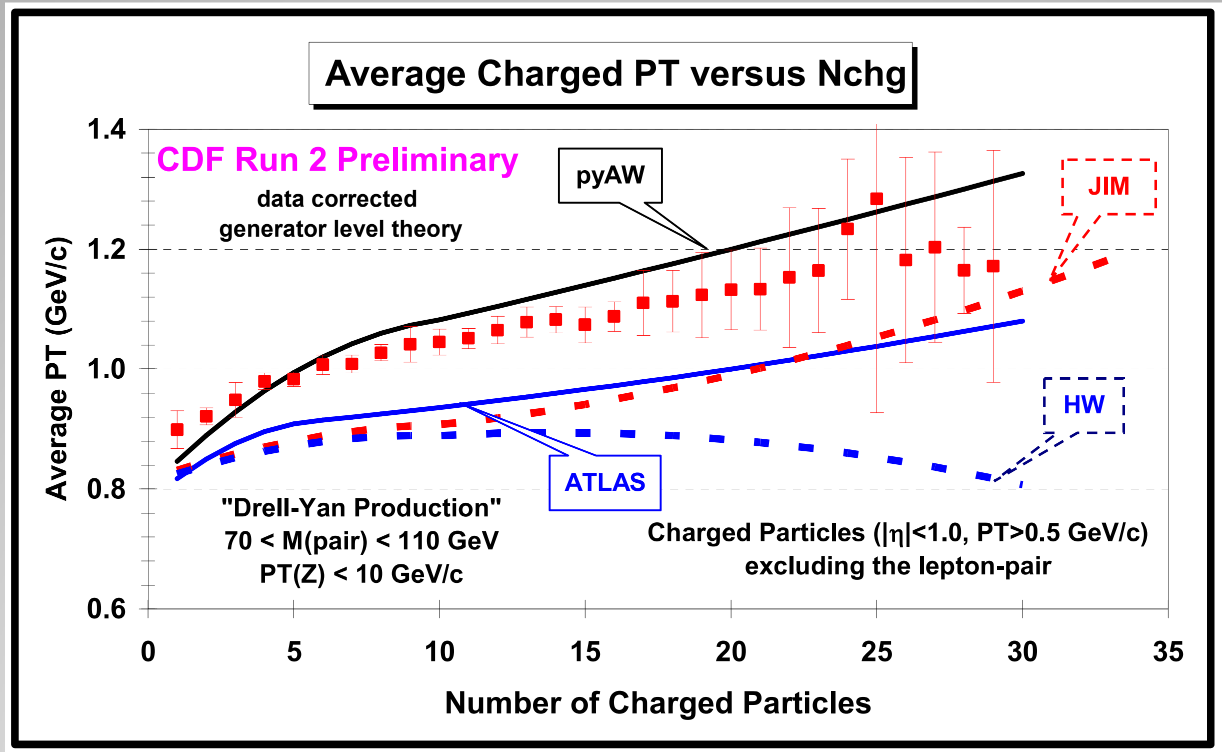
Mean p_T vs Charged Multiplicity



Large N_{chg} implies high p_T jets (i.e. hard 2→2 scattering). Without MPI the only way to get large N_{chg} is to have a very hard 2→2 scattering.

Mean p_T vs Charged Multiplicity

$P_T(Z) < 10$ GeV/c



Multiple-parton interactions provides another mechanism for producing large multiplicities that are harder than the beam-beam remnants, but not as hard as the primary Z +jet hard scattering.

Moving Forward to LHC

- The UE measurement plan at the LHC benefits from the solid experience of the CDF studies.

- Predictions on the amount of activity in transverse region at the LHC are based on extrapolations from lower energy data (mostly from the Tevatron).

- All the UE models have to be tested and adjusted at the LHC, in particular we know very little about the energy dependents of MPI in going from the Tevatron to the LHC.

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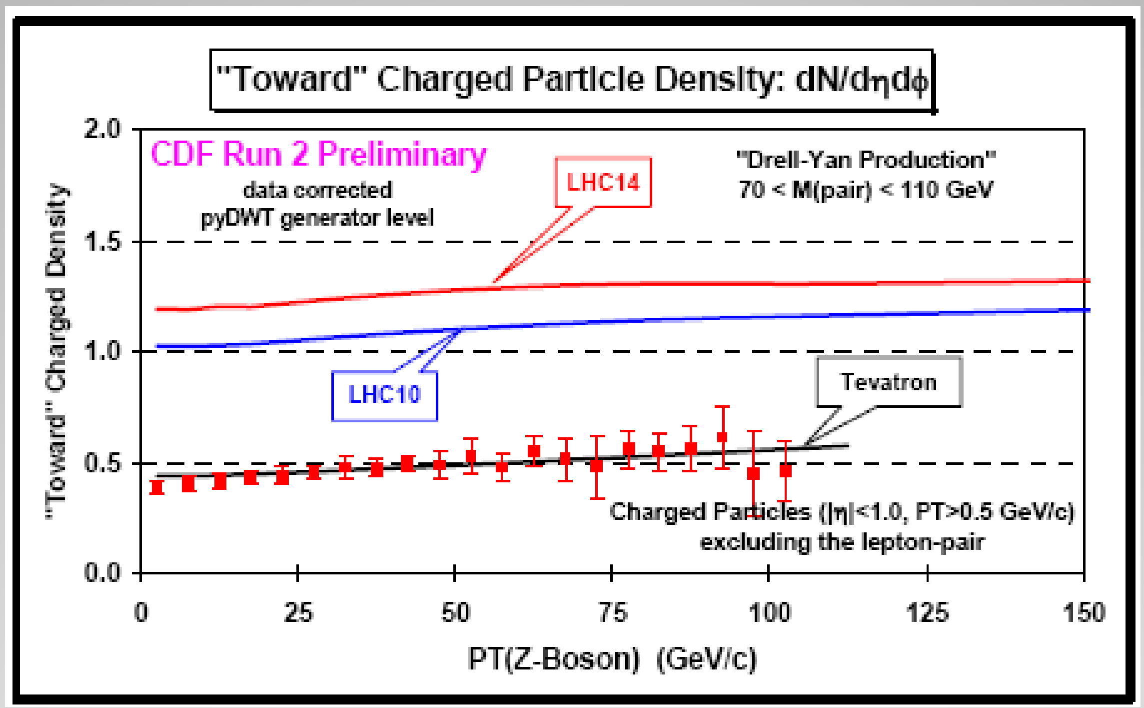
Few hundred pb^{-1} integrated luminosity in first year – enough Z's to look at the UE with Drell-Yan / Z+jets …

Moving Forward to LHC



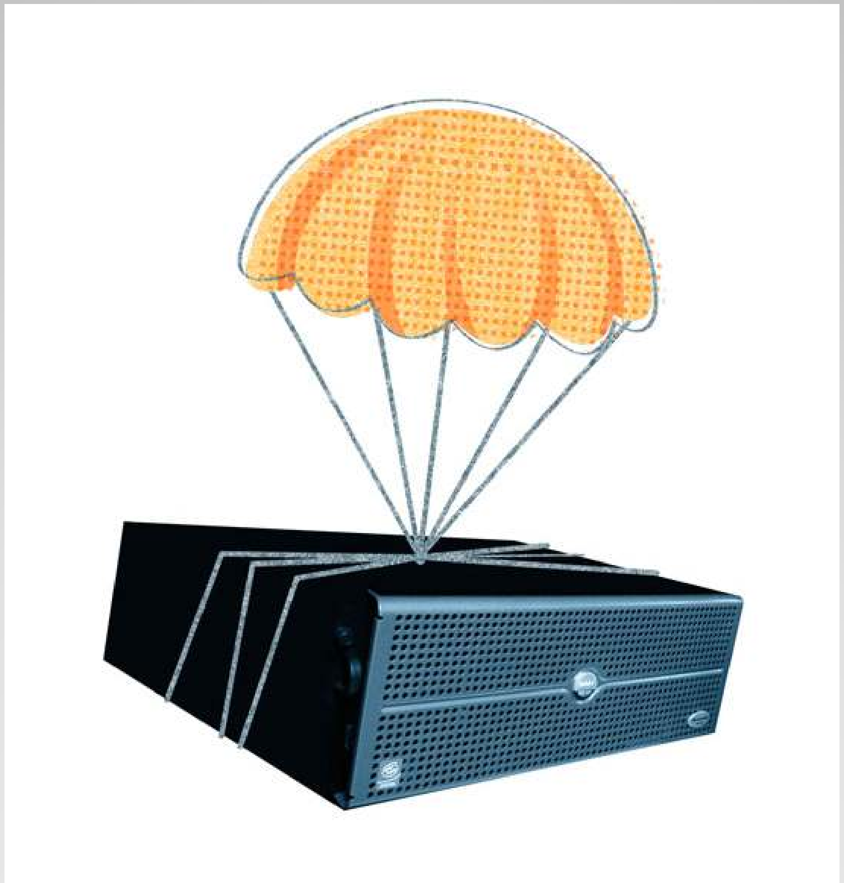
Underlying Event much more active at LHC

Conclusions

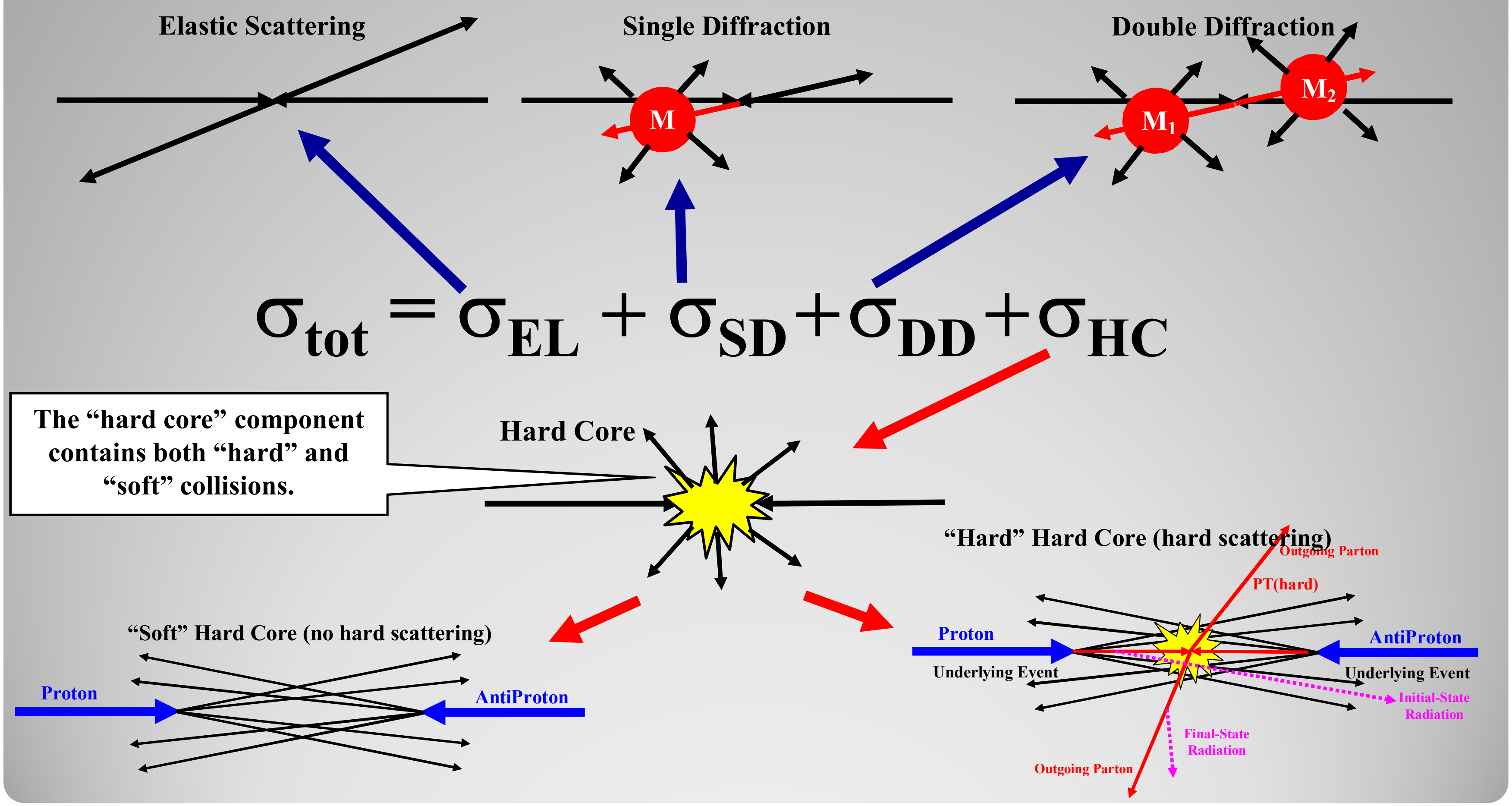
- Observed excellent agreement with PYTHIA tune AW predictions.
- Close match with leading jet underlying event results –underlying event models (BBR part) independent of hard scattering event?
- By looking at the correlation between $\langle p_T \rangle$ and charged multiplicity, we can discriminate between different contributing subprocesses.

As seen in Madison, WI

Backup Material



Proton-AntiProton Collisions at the Tevatron



Minimum Bias Event

- Events collected with a trigger that is **not very restrictive** – ideally with totally inclusive trigger.
- In principle contains all types of interactions proportionally to their natural production rate.

At the Tevatron about 1% of min-bias events contain a jet with 10 GeV transverse energy. At the LHC we expect this fraction ***increase*** *by more than a factor of 10.*

The Underlying Event in a Hard-Scattering Process is not the same as Min-Bias Events

- The underlying event produces tracks in the detector and energy in the calorimeter, thus affecting the measurement of the hard scattering component.
- Presence of initial and final state radiation.
- Color interactions between the hard scattering and the underlying event might occur.

Tuning PYTHIA

- Need to produce **tunes**, not of one parameter at a time, but simultaneously for a group of them.

- Given the many PYTHIA parameters to be tuned, it is convenient to divide the task into **subtasks**.

1. If we assume jet universality, **hadronization and final-state parton** showers should be tuned to e^+e^- annihilation data, notably from **LEP1**, since this offers the cleanest environment.
2. With such parameters fixed, **hadron collider data** should be studied to pin down **multiple interactions** and other further aspects, such as **initial-state radiation**.

Bringing PYTHIA in Good Agreement with the Data …

- The initial state radiation had to be adjusted.
- The dependence of the probability of multi-parton (secondary) interactions on the impact parameter had to be smoothed out.
- Probability of di-gluon production in multi-parton secondary interactions had to be substantially enhanced over di-quark production.
- The probability of color connections of products of secondary interactions with $p\bar{p}$-remnants had to be increased.

Soft QCD phenomena in events with high-ET jets at Tevatron - Andrey Korytov, Eur Phys J C 33, s01, s425–s426 (2004)

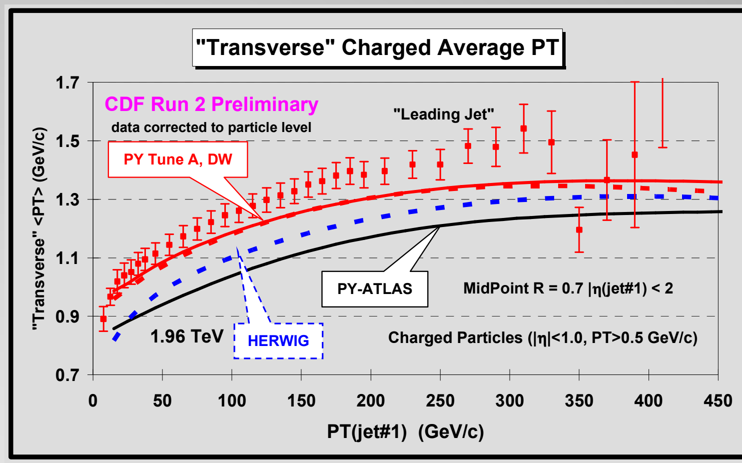
CDF Run 2 Tune (PYTHIA 6.206 CTEQ5L)

UE Parameters

ISR Parameters

Intrensic KT

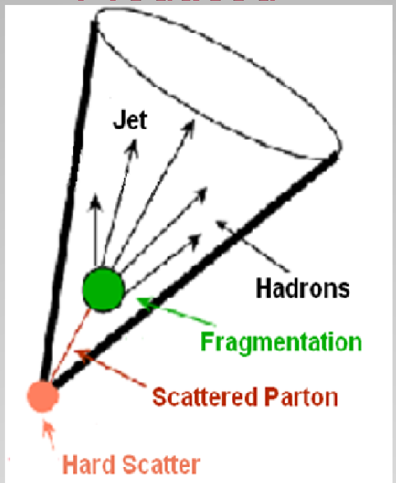
Parameter	Tune A	Tune DW	Tune DWT
MSTP(81)	1	1	1
MSTP(82)	4	4	4
PARP(82)	2.0 GeV	1.9 GeV	1.9409 GeV
PARP(83)	0.5	0.5	0.5
PARP(84)	0.4	0.4	0.4
PARP(85)	0.9	1.0	1.0
PARP(86)	0.95	1.0	1.0
PARP(89)	1.8 TeV	1.8 TeV	1.96 TeV
PARP(90)	0.25	0.25	0.16
PARP(62)	1.0	1.25	1.25
PARP(64)	1.0	0.2	0.2
PARP(67)	4.0	2.5	2.5
MSTP(91)	1	1	1
PARP(91)	1.0	2.1	2.1
PARP(93)	5.0	15.0	15.0



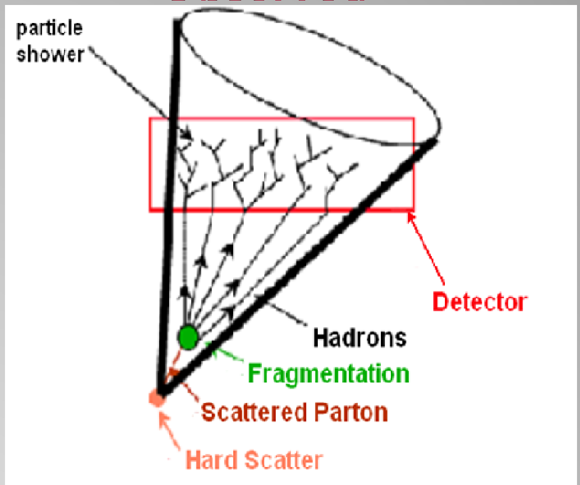
PYTHIA Tune DW is very similar to Tune A except that it fits the CDF $P_T(Z)$ distribution and it uses the DØ prefered value of PARP(67) = 2.5.

Steps Are:

Produced

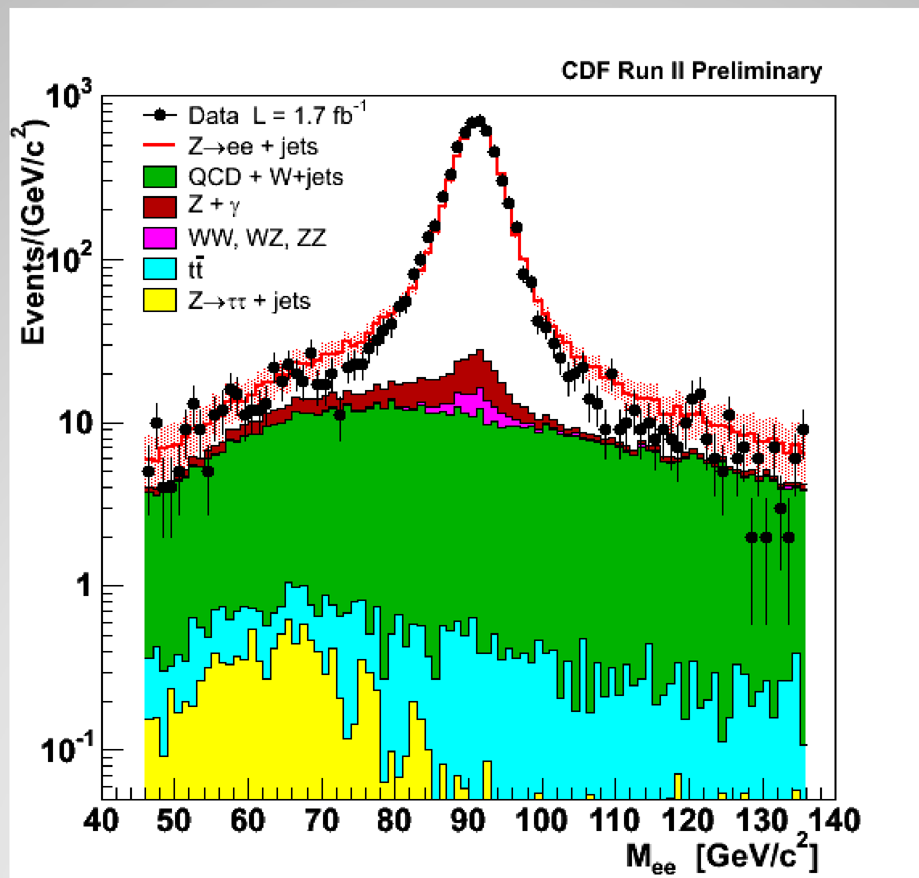


Observed



1. Calculate the observables by Monte Carlo event generator in **particle level** and in (by running through CDFSIM) **detector level**.
2. **Correct** the observables **back to particle level** in real data by calculating the **correction factor** from Monte Carlo.
3. **Compare** with different Monte Carlo event generators (PYTHIA, HERWIG…).

Negligible Background at "Z"



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